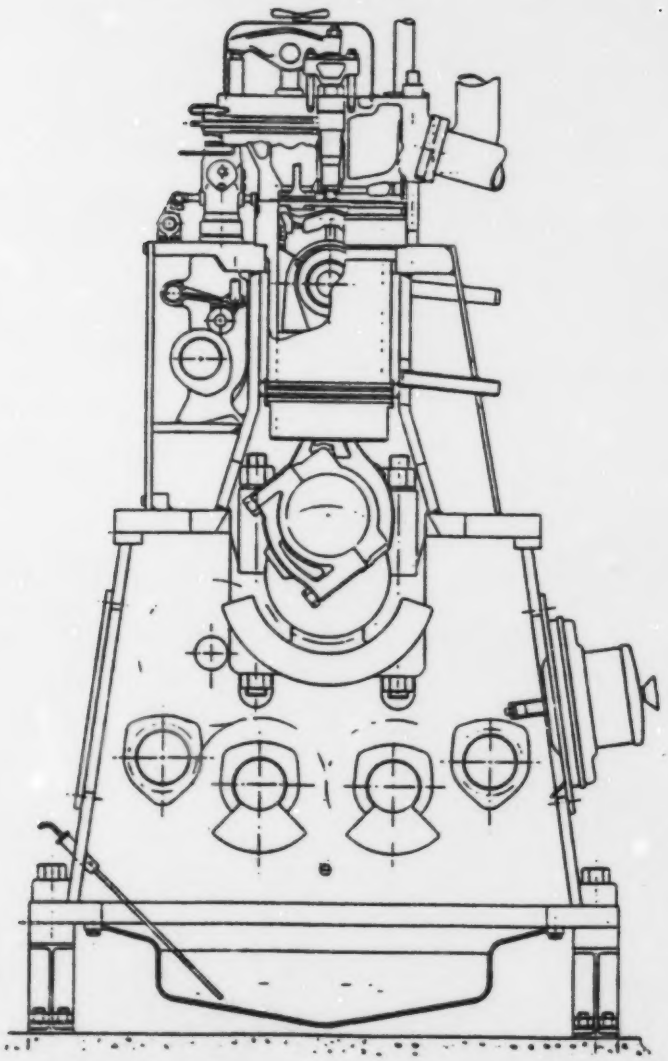
T.P. 4944E
Addendum

DESIGN OF A SINGLE CYLINDER MEDIUM SPEED RESEARCH ENGINE AND TEST FACILITY



Prepared for the
Transportation
Development Centre
by
Bombardier
Rail and Diesel
Products Division

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ADDENDUM TO REPORT TP 4844 E

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Transport Canada / Transports Canada

DESIGN OF A SINGLE CYLINDER MEDIUM SPEED RESEARCH ENGINE AND TEST FACILITY

MANUFACTURE OF SINGLE CYLINDER ENGINES

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BOMBARDIER INC.

MARCH 85

THE CONTENTS OF THIS REPORT REFLECT THE
VIEWS OF THE CONTRACTOR AND NOT NECESSARILY
THE OFFICIAL VIEWS OF THE TRANSPORTATION
DEVELOPMENT CENTRE

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 4844 E	4558/4840	

4. Title and Subtitle	5. Report Date
Design of a Single Cylinder Medium Speed Research Engine and Test Facility - Addendum	March 1985
	6. Performing Organization Report No. 484100
7. Author(s)	8. Transport Canada File No.
M.L. Payne	D1465-372-2-1
9. Performing Organization Name and Address	10. DSS File No.
Bombardier Inc. Engine Research & Development Dept. Rail & Diesel Products Division 1505 Dickson, Montreal, Quebec H1N 2H7	09SD.T8200-1-1560
	11. DSS or Transport Canada Contract No. 0SD81-00161
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre (TDC) Complexe Guy Favreau 200 Dorchester Blvd. West Suite 601, West Tower, Montreal, Quebec H2Z 1X4	14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer Roy S. Nishizaki

17. Abstract

This document reports on the manufacture of two single-cylinder engines designed for research into alternative and future fuels for diesel engines. The engines are representative of two medium - speed diesel engines of Bombardier Inc. design, the Model 251 and the new Model B 2400.

18. Key Words	19. Distribution Statement
Single cylinder diesel research engine, medium speed, direct injection, test facility	Limited number of copies available from TDC.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	9	nil

TDC/CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 4844E	4558/4840	

4. Titre et sous-titre	5. Date du rapport
Design of a Single Cylinder Medium Speed Research Engine and Test Facility - Addendum	mars 1985
	6. N° du rapport de l'organisme exécutant 484100
7. Auteur(s) M.L. Payne	8. N° de dossier Transports Canada D1465-372-2-1
9. Nom et adresse de l'organisme exécutant Bombardier Inc. Dépt. Recherche & Développement des Moteurs Division des produits ferroviaires et diesel 1505 Dickson, Montréal, Québec H1N 2H7	10. N° de dossier — ASC 09SD T8200-1-1560
	11. N° de contrat — ASC ou Transports Canada OSD81-00161
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) Complexe Guy Favreau 200 ouest, boul. Dorchester Suite 601, tour ouest Montréal, Québec H2Z 1X4	13. Genre de rapport et période visée
	14. Code de l'organisme parrain
15. Remarques additionnelles	16. Agent de projet — CDT Roy S. Nishizaki

17. Résumé

Ce document traite de la fabrication de deux moteurs monocylindres diesel destinés à la recherche de nouveaux combustibles. Ces moteurs sont représentatifs des deux moteurs semi-rapides de Bombardier Inc., le modèle 251 et le nouveau modèle B2400.

18. Mots-clés	19. Diffusion
Moteur de recherche diesel monocylindre, moteur semi-rapide, injection directe, installation d'essais	Le CDT dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non classifié	non classifiée	9	aucun

CDT/TDC 79-005

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INTRODUCTION

At the completion of the Design Phase of the Bombardier Single Cylinder Research Engine Programme a cost analysis showed that there was a surplus of funds. A preliminary estimate indicated that this amount could cover the cost of engine manufacturing. An amendment was made to the contract which added this activity.

It should be pointed out that the final cost was reduced by incorporating in the design a greater number of existing components than was initially estimated, i,e, Pistons, cylinder head assemblies, cams etc. Also during the interim, in-house computer analysis capability had reached a level which avoided the expenditure of allocated rental and consultant fees. However, this advantage was absorbed by significant increases in both engineering and shop labour.

This report outlines the methodology and some of the processes which were required to bring into reality the Bombardier Single Cylinder Research Engines.

MANUFACTURING

The conceptual design of the Bombardier Single Cylinder Research Engine (BSCRE) provides for a wide range of research applications due to its inherent flexibility.

The first step was to decide what research projects in the R&D Program would be allocated to the BSCRE in near term. The requirements for this list of projects formed the engine configuraion specification and in turn the detail design of the components.

The next step was a complete review of the component documentation, (drawings and specifications). The drawings made during the Design Phase were submitted to the Industrial Engineering and Manufacturing departments for comments, from which it was determined that drawings more suitable for component manufacture would have to be made.

The estimated amount of time and engineering effort to create drawings more suitable for manufacturing was considerable and contributed substantially to overshooting of the budget. Compromises, such as using design layouts for the assembly of fuel and exterior lube oil piping, made and only the components which required special tooling or modification to suit our application were redrawn.

All engine components were separated into three groups - shop made (in-house), long-lead time purchase parts and normal lead time purchase parts. The release for quotation of the long-lead items (crankshafts, gears, and the engine base cast steel cross-webs) was made by the Purchasing department followed by release of the remaining purchased parts.

The third group of items, those made in-house, required the greatest amount of effort since there was no shop experience existing and the additional learning curve proved to be substantial. Reports from the Production Control group showed that in some cases it took four times the original allocated man hours to make special parts. The attitude taken in the shop was a cautious one, resulting in delays while they waited for enginnering acceptance between welding operations on the block and bottom end. Also in the weldment fabrication stage some plates were re-configured to a more practical shape. All of this additional effort was not foreseen at the on-set, specifically the increased scope of engineering participation.

Unfortunately, because of shop loading, both engines, (1-B2400 & 1-251) could not be made side by side. Problems peculiar to the 1-251 design arose during the fabrication of the 1-251, and, because of the differences only some of the experience taken from the 1-B2400 engine was successfully applied.

The engine consists of two main welded assemblies, the cylinder block (top end) and the base (bottom end) to which the piston, connecting rod and cylinder head are fitted. The cylinder block is a welded steel plate fabrication which is subsequently machined. During the welding stage it was found that the sequence of some operations as dictated by the manufacturing Operation Layout Sheets (OLS) had to be adjusted. The adjustment was found necessary to avoid thermal distortion at some critical locations. Also as the fabrication progressed it became obvious that changes were required for certain weld type specifications in order to successfully complete some of the welded assemblies. All of the changes were made to the OLS and the drawings revised. After the completion of the block weldment, it was stress relieved, which involves heating in the furnace for approximately twelve hours at a temperature of 1050°F then allowing to cool slowly to room temperature. This operation was considered critical since built-in thermal stresses, if significant, would cause dimensional changes which could make the weldment unuseable. The machining of the block was done in two stages because of the critical relationship of the camshaft bores in the top end and the crankshaft main bearing bores in the bottom end. Only preliminary machining was done at this point.

The fabrication of the base passed through an exercise similar to that of the block described above. The base is a more massive structure it is designed to handle (dampen) severe vibratory loads and support the whole engine. The welding and stress relieving of this component progressed according to the OLS's without significant changes and then it was completely machined. The engine is of the "bed plate" design i.e. crankshaft is located in the lower (engine base) structure instead of "under slung" in the block. Also four (4) counter-rotating balance shaft are situated relative to the crankshaft in this structure. A fixture was made so that the bores of all five (5) shafts which must be

held within plus or minus 0.0015 would be maintained. (See Figure 1)

The critical dimensional relationship between the crankshaft and the camshaft was controlled by bolting the block to the base at final assembly before finish machining the cam bores relative to the crank bore. The final block machining was also performed during this setup.

The subsequent steps consisted of:

- Complete dimensional inspection
- Disassemble the block from the base
- Fit cylinder liner
- Water test the block
- Fit cylinder head holding studs
- Fit cam bushings in block
- Fit balance bushings
- Install balance bushing
- Install crankshaft
- Fit crank balance shaft gear train

At this juncture the two main assemblies were moved to the test cell where they were assembled (bolted together) after which the following items were fitted:

- Camshaft
- Cam gear drive train
- Piston and connecting rod assembly
- Cylinder head
- Valve gear
- Fuel pump
- Electronic governor
- Oil sump
- Miscellaneous covers

- Pressure relief safety valve
- Flywheel/ring gear
- Air start motor.

It should be noted that the power assembly (piston, connecting rod and cylinder head assembly) components were taken from stock, therefore the manufacture of these items is not included in this report. During the assembly process all components were measured. Fits and clearances, fastening torques, and gear train backlash measurements were recorded. Adjustments were made where necessary and drawings revised to suit.

Although layouts were made of the fuel and lube oil piping, except for headers and manifolds, the piping was done in situ. The piping was done in this manner since it was easier to chose the best route and location.

COST ANALYSIS (engine manufacture)

	TASK	ESTIMATE	ACTUAL
1-	Project Management	7,000.	17,200
2-	Engineering	16,500	112,300
3-	Material	58,000.	98,600.
4-	Tooling	4,000.	23,000.
5-	Fabrication	18,500.	114,000.
6-	Assembling	4,000.	46,500.
		$108,000.	$411,600.
	Per engine	$ 54,000.	$205,800.

The above breakdown shows the considerable discrepancy between the estimated and actual costs when totalled approximately two years later. Some of the increase was due to labor and overhead rate changes. The most significant contributors, however, were the labor or time intensive tasks namely engineering, fabrication and assembling.

The estimate was made with the expectation that the drawings prepared during the Design Phase were suitable for manufacture and that no additional or unique tooling would be required. It was also based on material and time, not including overhead and fringe benefit charges where applicable. The current cost to produce one (1) BSCRE with all factors applied is approximately eighty (80) percent of the actual cost shown above.

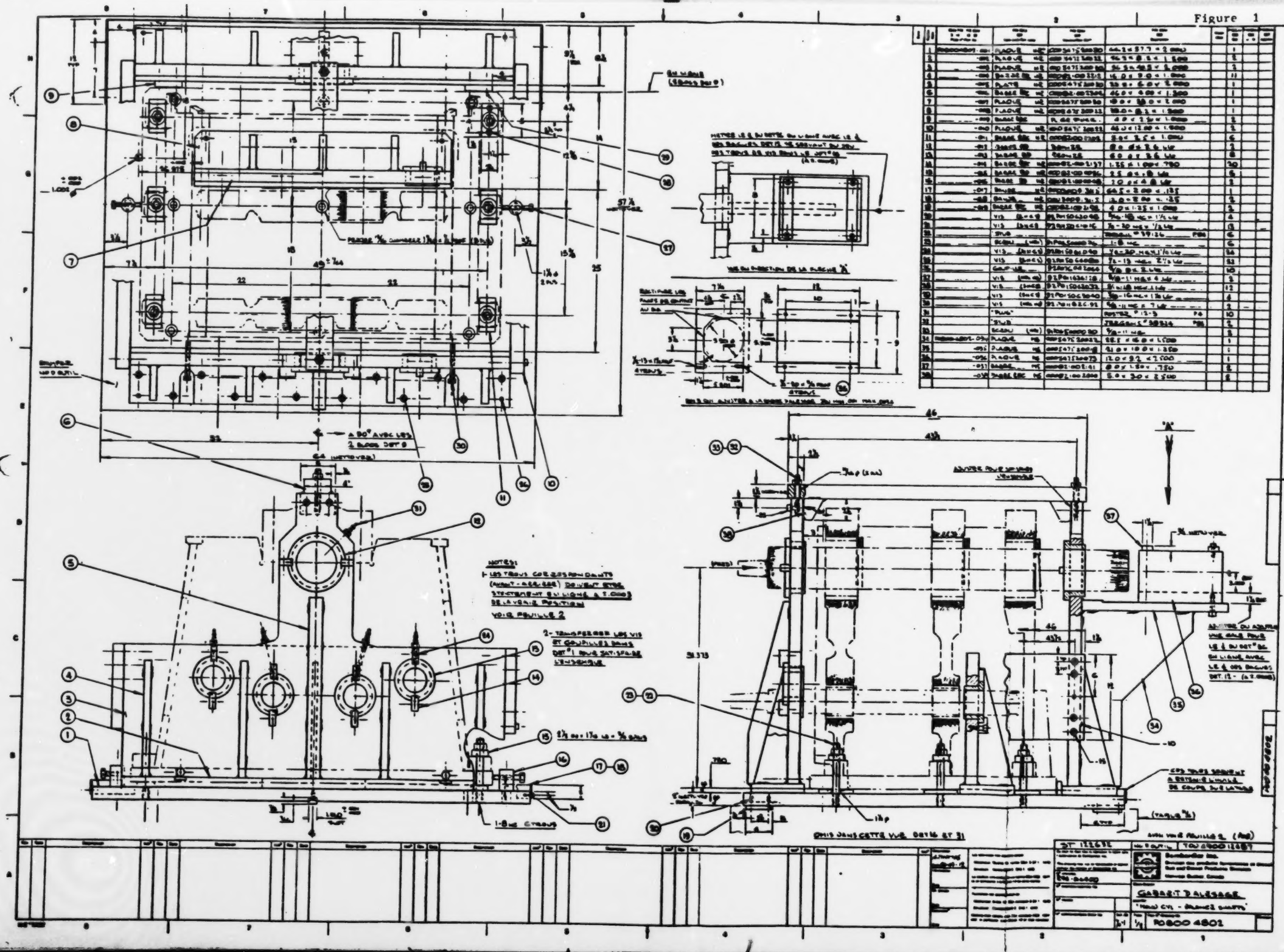
CONCLUSION AND RECOMMENDATIONS

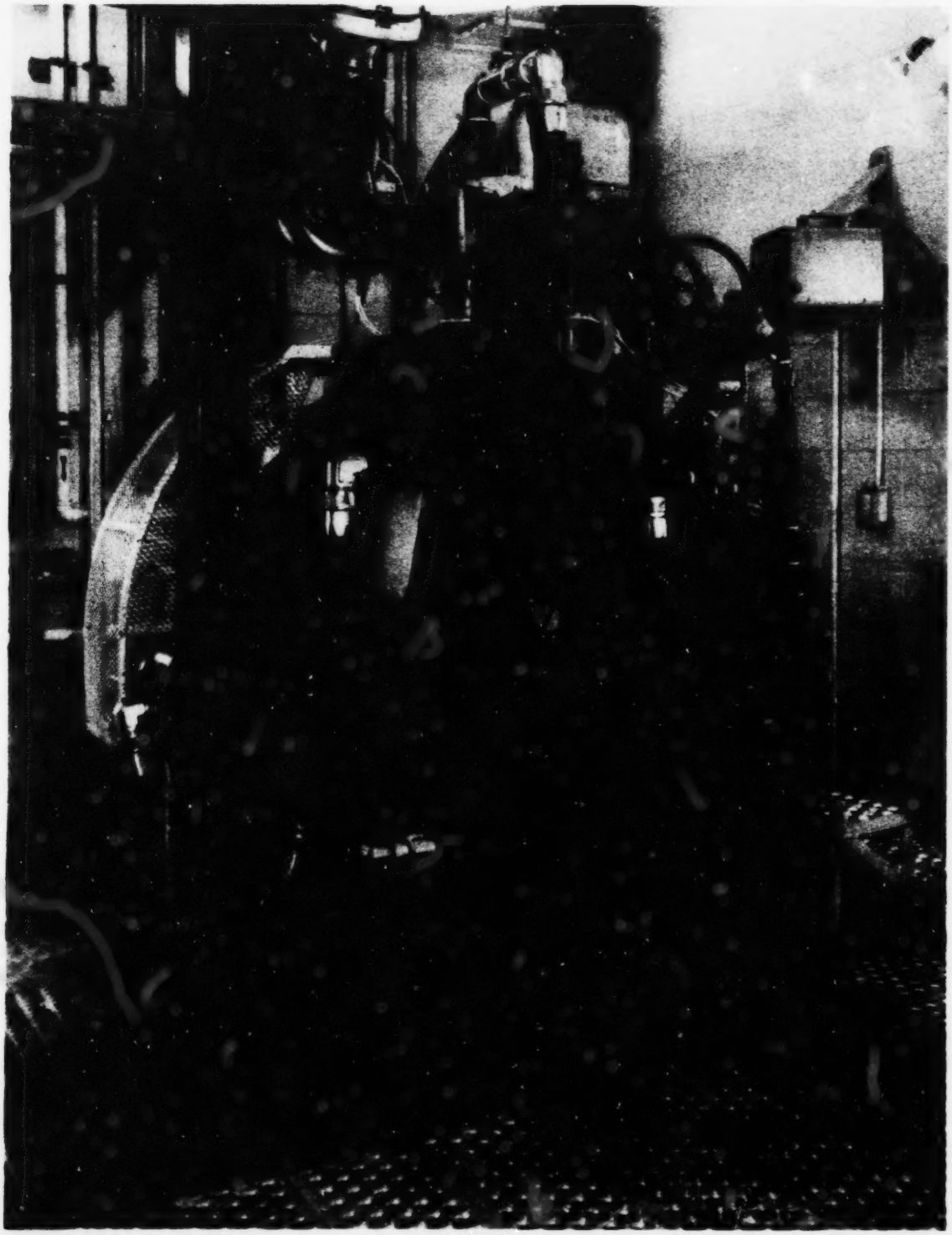
This report which addresses only the manufacturing portion of the Single Cylinder Engine Programme also completes Phase I and the conclusions and recommendations which follow apply only to the engine manufacture.

- From an overall point of view no major difficulties were encountered with either the 251 or B2400 versions.
- The concept of having two engine designs with a common bottom-end has proven to be a viable approach. The flexibility of the bed plate design allows for numerous bore/stroke combinations.
- Although several methods (less costly) were considered to maintain the dimensional accuracy between the cam bore in the top-end and the crankshaft, idler and four (4) balance shaft bores in the bottom-end, the accuracy achieved using the one piece, one setup fixture cannot be disputed. (See Figure 2)
- It must be concluded that the major portion of the difference between the actual cost to manufacture the engines and the original "extremly optimistic" estimate can be attributed to an ill-advised attempt to confine the estimate within the frame work of the then existing funding.
- These engines must be considered as prototypes and additional funds must be allocated to incorporate future improvements and modifications some of which are already visualized.
- Start-up of the 1-B2400 has taken place verifying the basic design. But it must be recognized by all parties that all necessary work is not yet finished. Until reliable and consistant performance has been attained as expected from a research engine of this type.

The total cost of Phase I which covered the design of 1-B2400 and 1-251 engines, design of the test facility and manufacture of the two engines was $785,841. This was estimated in 1982 to be $458,898. with TDC's then 84% funding of $385,474. Due to the fixed upper limit of TDC participation, the actual TDC contribution to this Phase I project is now calculated at 49% of the total cost.

Figure 1





– FIGURE 2 –
I-B2400
(BSCRE-001)